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EXHAUST CONTAMINATION IN PASSENGER CARS

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Robert A. Taft Sanitary Engineering Center
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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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EXHAUST CONTAMINATION IN PASSENGER CARS

Summary

A preliminary test program has been made to investigate some basic factors affecting the concentration of exhaust gas inducted into the passenger compartment of an automobile by the forced ventilation system. With the small number of tests run, it is not intended that the values developed be interpreted as statistically "normal" but rather as an indication of possible levels and trends.

Tests were run on grouped moving vehicles and on grouped stationary vehicles to simulate heavy traffic conditions. Exhaust concentrations in the passenger compartment of vehicles under moving traffic conditions were slightly above the background curbside levels. Stationary traffic conditions with vehicles grouped at average intervals produce marked increase in exhaust concentrations with the highest recorded at 0.8%[370 ppm carbon monoxide (CO)] of the raw exhaust value. In moving vehicles, the highest value recorded was 0.04% (20 ppm CO) above the curbside level.

The location of the forced ventilator inlet was shown to exert a significant effect on the exhaust concentration in the vehicle passenger compartment. Front inlets as contrasted to cowl and side inlets consistently gave higher values. Stability and movement of the air mass circulating around the stationary vehicles was the second factor exerting a significant influence on passenger compartment concentration. No significant effect was indicated by the differences in exhaust tailpipe location as used in present day automobiles. A vertical exhaust system (extended to car top level) gave essentially zero passenger compartment concentration.

NOTE: Mention of commercial devices in this report is not to be construed as an endorsement of them by the Public Health Service.

Objectives

The objective of this study was to make a preliminary investigation of the relative amounts of exhaust gases inducted into the passenger compartment of a vehicle by the forced ventilation system when the vehicle is operating in city traffic. Two basic driving conditions are representative of "stop and go" city traffic patterns; first, low speed operation with slow cruise, mild accelerations and mild decelerations; and second, stationary operation at idle with the vehicles grouped with minimal interval between vehicles as if stopped at a traffic light or in a traffic tie-up. Under heavy traffic conditions, when the effect of inducted exhaust gases in the passenger compartment is greatest, traffic conditions generally result in a minimum of two cars abreast.

Test Procedures

All tests used to determine passenger compartment exhaust gas concentrations employed four vehicles positioned two abreast. The two forward vehicles furnished the controlled exhaust gases, and compartment concentrations were determined in the two following test vehicles. Three types of forced ventilation inlets were studied. One type was located just above the headlight. Another was on the cowl ahead of the windshield, and the third was on the side of the vehicle at a position about two-thirds of the distance towards the rear of the car.

A comparison also was made of exhaust or tailpipe location effect. A standard exhaust system which discharges the exhaust gases downward towards the road bed was compared with both a bumper type exhaust system in which the exhaust gases are vented horizontally at bumper level, and with an exhaust system extended vertically to the height of the vehicle top, from which the exhaust gases were discharged upward at car top level.

For both the moving and stationary tests, measurements were made of the carbon monoxide (CO) concentrations in the raw exhaust gases in the forward cars and of the CO concentrations in the passenger compartments of the rear or "test" cars. The amount of exhaust gases inducted into the test cars by the forced ventilation system was calculated, based on CO concentrations, as percentage of raw exhaust gases introduced into the passenger compartment of the test cars.

The procedure used for the stationary tests was to position the vehicles, with engines at idle, ventilation system blower on full, and car windows closed, and hold the conditions until readings of CO concentrations at the driver position in the test cars and in the exhaust of the lead cars could be taken. Approximately one minute was required for the instruments to stabilize. This procedure was repeated for different combinations of ventilation inlets and tailpipe locations, and for two directions of vehicle position relative to wind direction.

Moving tests were made with the four vehicles driving two abreast at approximately 20 mph. CO concentrations were taken continuously with the ventilation system blower on full and car windows closed during runs over a one-half mile course in opposite directions.

Because of the importance of meteorological conditions in the results, it was necessary to conduct the tests during periods of extremely stable air conditions. This reduced the available test time to the period from dawn to the point when the diurnal inversion would break, which averaged about two hours. No tests were run when the wind exceeded one mile per hour. This further limited the available test periods to about one day per week.

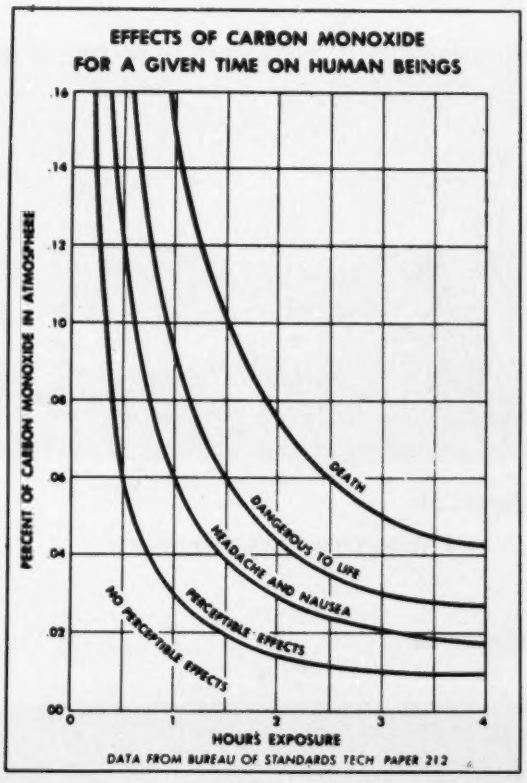
The instrument used to measure CO concentration in the passenger compartment was a type[1] which senses the temperature rise due to oxidation of carbon monoxide in a "Hopcalite" cell. The instrument for measurement of CO in the exhaust was a nondispersive infrared detector.[2] The instruments read 0 to 1000 ppm and 0 to 8 percent full scale, respectively. The exhaust plumes were sometimes augmented with smoke candles to observe their travel visually.

Discussion

It is not intended that the values developed in this study be interpreted as "normal" values, since the number of experiments required to establish normal distribution and standard deviation were not attempted. Rather, a few sample values were obtained to indicate possible levels and trends. Conditions for maximum concentration in the passenger compartment were chosen, i.e., early morning with calm stable air so that high values would be obtained, since these are the levels of interest in this study.

Observed values of CO should be considered in the light of possible physiological effects. An exposure-time-concentration basis is given in the accompanying graph.[3] Cognizance must be taken that the effects shown for various time concentrations in the graph refer to average, healthy persons, and that the degree and severity of exposure and consequent effect vary according to changes in respiratory rate, pulmonary and cardiac function, and other factors.

The American Conference of Governmental Industrial Hygienists has set a maximal allowable concentration for industry of 100 ppm CO for an eight hour day. For ambient (community) air, the California State Department of Public Health has set 30 ppm of CO for an eight-hour day and 120 ppm of CO for one hour as standards.



1. MSA CO Indicator.
2. Beckman L/B Model 15A.
3. U. S. Bureau of Standards, Technical Paper 212. 0.10% CO equivalent to 1000 ppm.

In order to determine the optimum test program to be run in the limited time available, some exploratory studies of both moving and stationary traffic conditions were made, using grouped and individual test cars. Studies of the moving traffic conditions employing grouped vehicles, Figures 1a and 1b, were made while the cars were traveling at 20 mph with normal space intervals. Smoke candles were used in the exhaust pipe of the right front car to allow an evaluation of this effect to be made.

Figure 1a

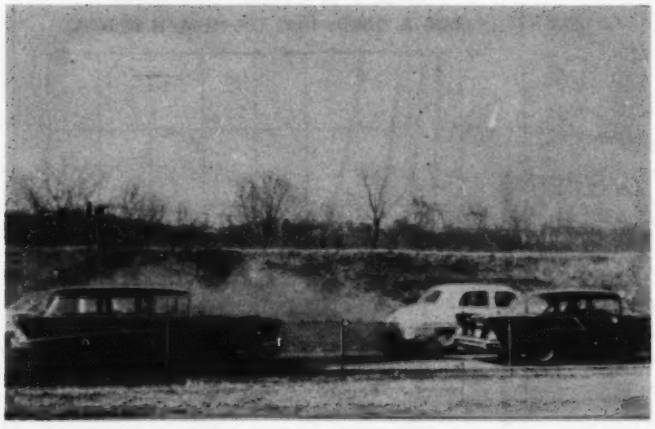


Figure 1b

Based on the turbulent expansion of the smoke plume, it can be shown that in the time interval necessary for the trailing vehicle to reach the plume from the forward vehicle, a dilution of approximately 3000:1 took place. This results in an exhaust concentration of about 7 ppm in a passenger compartment, as measured by a CO concentration. This low level was further confirmed by driving in actual city traffic and then comparing passenger compartment concentration with curbside concentration. In no test was there evidence in the vehicle passenger compartment of more than 20 ppm above background level. It was concluded that inducted exhaust concentration build-up in the passenger compartment of moving vehicles is not sufficiently high to create serious problems.

The second phase of the study was made on stationary vehicles grouped to simulate traffic signal, railroad crossing or other traffic tie-up conditions, Figures 2, 3, and 4.

MOVING TRAFFIC STUDIES

Figure 2a

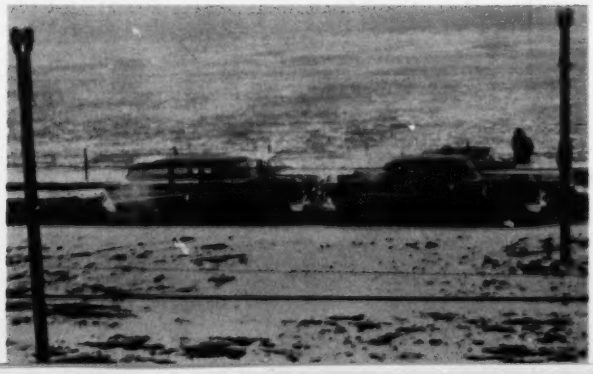


Figure 2b

Figure 3a

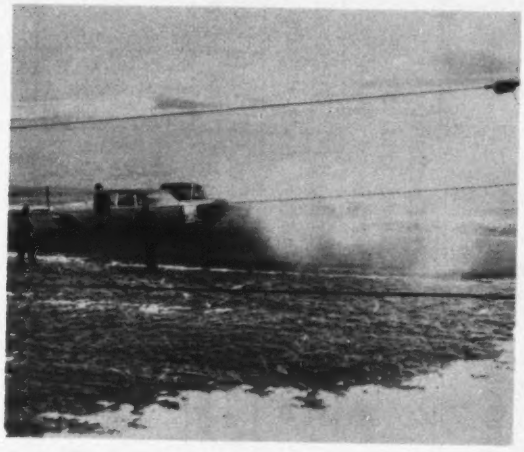


Figure 3b

Figure 3c

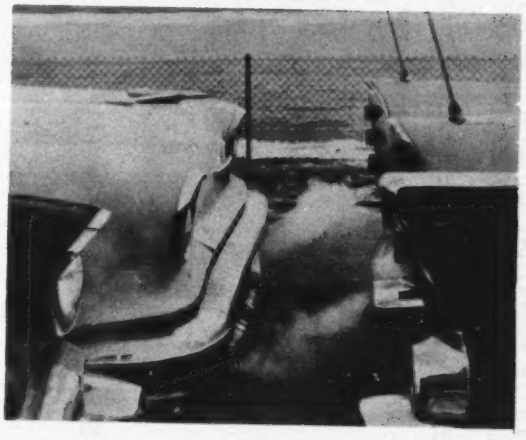


Figure 3d

STATIONARY TRAFFIC STUDIES - Test 2

Within the limited scope of this study, not all possible arrangements were measured, but the various test conditions were selected to illustrate the effect of wind movement as well as the four most probable conditions of exhaust location and ventilator inlet position encountered with present day cars under average traffic conditions. Three test series are presented. Table 1 covers a standard automotive exhaust system in which the exhaust gases are vented downward toward the road bed, and a bumper discharge exhaust system in which the gases are exhausted horizontally at bumper level. Table 2 covers the effects of wind drift.

Figures 2a and 2b
STATIONARY TRAFFIC STUDIES - Test 1

Table 1. EFFECTS OF VENTILATION INLET AND EXHAUST POSITION ON PASSENGER COMPARTMENT EXHAUST CONCENTRATIONS

Test series and car headings	Range of CO percentage in exhaust of forward car	Wind drift or air motion	Passenger compartment measured concentration CO, ppm						Calculated percent exhaust concentration in passenger compartment					
			Bumper exhaust		Standard exhaust		Vertical exhaust		Bumper exhaust		Standard exhaust		Vertical exhaust	
			Front inlet	Cowl inlet	Front inlet	Cowl inlet	Front inlet	Cowl inlet	Front inlet	Cowl inlet	Front inlet	Cowl inlet	Front inlet	Cowl inlet
Test 1														
East	7.2 - 7.2	NW to SE			185	115					0.3	0.15		
Test 2														
East	4.0 - 4.6	N to S	165	0	370	65			0.4	0.0	0.8	0.15		
West	3.6 - 4.3		155	35	20	0			0.4	0.1	0.05	0.0		
	3.6 - 5.7		200			0			0.4			0.0		
	4.0 - 5.1		310			30			0.7			0.05		
Test 3														
East	3.7 - 4.8	NE to SW	265	15	65	30	15	0	0.6	<0.05	0.15	0.05	<0.05	0.0
West	4.1 - 4.5			115	50		15	15		0.3	0.1		<0.05	<0.05

Figure 4a

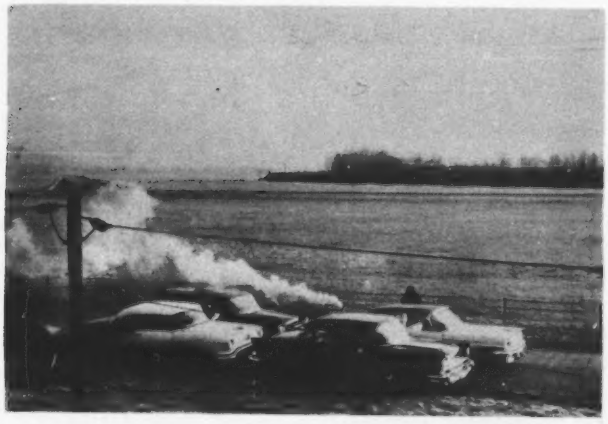
Figure 4b

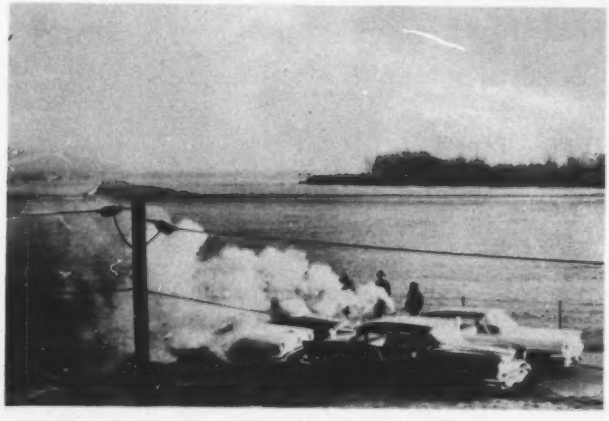
STATIONARY TRAFFIC STUDIES - Test 3

The first significant trend indicated by the data, Table 1, relates to the location of the forced ventilation system inlet. In general, the inlet located in the front of a vehicle as contrasted with either the cowl location or side location gave substantially higher concentrations of exhaust gases in the passenger compartment. This trend was consistent for either the standard exhaust system or the bumper type exhaust system. Data for the side location of the forced ventilation inlet, while not shown in Table 1, indicate no detectable difference from the values obtained with the cowl inlet location. The effect of exhaust location also was investigated using, first a standard type exhaust system in

Table 2. EFFECT OF AIR MOVEMENT ON PASSENGER COMPARTMENT EXHAUST CONCENTRATIONS

Test series	Measured concentration CO, ppm				Calculated percent exhaust concentration			
	Front ventilator inlet		Cowl ventilator inlet		Front ventilator inlet		Cowl ventilator inlet	
	Test car upwind	Test car downwind	Test car upwind	Test car downwind	Test car upwind	Test car downwind	Test car upwind	Test car downwind
Test 2	165	370	0	65	0.4	0.8	0.0	0.15
	20	155	0	35	0.05	0.4	0.0	0.1
Test 3	50	65	15	30	0.1	0.15	0.05	0.05
		265		115		0.6		0.3





Figures 5a and 5b. ELEVATED EXHAUST STUDIES

which the gases were discharged downward toward the road bed; second, a bumper type system in which the gases were discharged horizontally at bumper level; and third, an extended exhaust system from which the gases were discharged upward at car top level. No difference in passenger compartment concentration was evident between the two systems in common passenger car usage, i.e., the standard and bumper types, Table 1. The extended system, however, within the limitations of the test (Figures 5a and 5b) gave essentially zero passenger compartment concentrations under stable air conditions.

A second equally significant trend on passenger compartment concentration, under stationary traffic conditions, is the movement of the air mass conveying the exhaust gases between vehicles, Table 2. When the test vehicle is positioned downwind from the exhausts of the lead vehicles, the passenger compartment concentrations of exhaust gases, even under low wind velocities of less than one mile per hour, are several times higher than in vehicles in an upwind or sidewind position, Figure 4a. With greater wind velocity, concentrations in the passenger compartment dropped to essentially zero. In Figure 3d the far test

Figure 6a

Figure 6b

METEOROLOGICAL STUDIES

vehicle, in a sidewind position to the exhaust discharge, indicated zero concentrations while the near test vehicle in a downwind position resulted in exhaust gas concentrations of 0.8% of the raw exhaust concentrations of the lead cars. Evaluations of each of the other specific test conditions confirmed these findings, Table 1.

The effect of the stability of the air mass on the ventilator induced exhaust gases is illustrated in the action of the exhaust plumes, Figures 5 and 6. When the atmosphere is stable, the plume moves horizontally over the downwind cars, Figures 5a and 6a. Twenty minutes later the radiation from the sky towards the ground had increased over the radiation from the ground towards the sky, warming the lower layers of air. This reversal of radiation effect and the resultant warming of the lower levels of air cause vertical mixing as illustrated by the looping effect and vertical structure of the plumes, Figures 5b and 6b.

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